U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-268 740

Radionuclide Accumulation in a Reactor Cooling Lake

Eastern Environmental Radiation Facility, Montgomery, Ala

Jul 76

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-520/5-76-009	2.	3. Recipient's Accession No.
4. Title and Subtitle: Radionuclide Accumulation in a Reactor Cooling Lake			5. Report Date: July 1976
7. Author(s): R. L. Shearin, R. J. Lyon			8. Performing Organization Rept. No. EPA-520/5-76-009
9. Performing Organization Name and Address: Eastern Environmental Radiation Facility, P. O. Box 3009, Montgomery, Alabama 36109			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Address			13. Type of Report & Period Covered
			14.

15. Supplementary Notes

16. Abstract: In the utilization of a cooling lake for a commercial power reactor, low-level quantities of liquid waste are released to the lake water. Due to the retention and recycling of water for condenser cooling purposes, concentrations of radionuclides can increase to levels which are directly measurable in the water. Such a site design is represented by the H. B. Robinson Unit 2 operated by the Carolina Power and Light Company at Hartsville, SC.

For a 4-year period lake water and other lake components such as fish, aquatic vegetation, and benthic sediments were sampled and analyzed to determine if any long-term buildup occurred. Results indicated that the lake water concentrations followed general mixing equations and that turnover rates in the individual components of the lake were too short to quantitate with this study design. This indicates that concentrations of radionuclides in the lake would be primarily a function of parameters such as radioactivity released and lake flow for the previous year and essentially independent of earlier parameters. An estimate of annual external doses to an individual utilizing the lake for recreation (i.e., swimming, boating, and fishing) would be about 5 microrem.

17. Key Words:

17b. Identifiers/Open-Ended Terms:

17c. COSATI Field/Group:

18. Availability Statement:	19. Security Class (This Report): UNCLASSIFIED	21. No. of Pages: 80
	20. Security Class (This Page): UNCLASSIFIED	22. Price: $4.00/$2.00

EPA-520/5-73-009
PB 265 740

RADIONUCLIDE ACCUMULATION IN A REACTOR COOLING LAKE

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

NOT REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE

EPA-520/5-76-005

RADIONUCLIDE ACCUMULATION IN A REACTOR COOLING LAKE

M. L. Shearin

R. J. Lyon

Eastern Environmental Radiation Facility

P. O. Box 3009

Montgomery, Alabama 36109

July 1976

U. S. ENVIRONMENTAL PROTECTION AGENCY

Office of Radiation Programs

Waterside Mall East

401 M Street, S.W.

Washington, DC 20460

ii

FOREWORD

The Office of Radiation Programs carries out a national program designed to evaluate the exposure of man to ionizing and nonionizing radiation, and to promote the development of controls necessary to protect the public health and safety and assure environmental quality.

Technical reports allow comprehensive and rapid publishing of the results of Office of Radiation Programs' intramural and contract projects. The reports are distributed to State and local radiological health offices, Office of Radiation Programs' technical and advisory committees, universities, laboratories, schools, the press, and other interested groups and individuals. These reports are also included in the collections of the Library of Congress and the National Technical Information Service.

I encourage readers of these reports to inform the Office of Radiation Programs of any omissions or errors. Your additional comments or requests for further information are also solicited.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
for Radiation Programs

PREFACE

The Eastern Environmental Radiation Facility (EERF) participates in the identification of solutions to problem areas as defined by the Office of Radiation Programs. The Facility provides analytical capability for evaluation and assessment of radiation sources through environmental studies and surveillance and analysis. The EERF provides technical assistance to the State and local health departments in their radiological health programs and provides special analytical support for Environmental Protection Agency Regional Offices and other federal government agencies as requested.

This study is one of several current projects which the EERF is conducting to assess environmental radiation contributions from fixed nuclear facilities.

Charles R. Porter
Director
Eastern Environmental Radiation Facility

ACKNOWLEDGMENT

The authors acknowledge the invaluable assistance and notable cooperation provided by the South Carolina Department of Health and Environmental Control, Bureau of Radiological Health. The Bureau provided relative information, consultation, and liaison services and contributed a significant amount of manpower and field equipment.

The cooperation and assistance of the Carolina Power and Light Company employees, especially those at the H. B. Robinson Plant, is also acknowledged. Their supply of data resources, pertinent information and friendly cooperative spirit helped to accomplish this work.

The authors also recognize this report as a product of the entire staff of the Eastern Environmental Radiation Facility (EERF). Significant individual cooperation and team efforts contributed directly to make this work possible.

The EERF acknowledges the capable consultative support and field assistance provided by the headquarters staff of the Environmental Protection Agency, Office of Radiation Programs, Washington, DC.

CONTENTS

		Page
FOREWORD		iii
PREFACE		iv
ACKNOWLEDGMENT		v
ABSTRACT		ix
SECTION I.	INTRODUCTION AND OBJECTIVES	1
SECTION II.	STUDY SITE	4
	Power Plant	4
	Sources of Radioactivity Releases	5
	Lake Robinson	7
SECTION III.	STUDY METHODOLOGY	11
	Study Design	11
	Lake Survey	12
	Sampling	13
SECTION IV.	WATER	17
	Lake Model	17
	Evaluation of the Model for Tritium	19
	Downstream Dilution of Tritium	26
	Tritium in Well Water	28
	Gamma Emitting Radionuclides	29
	Cobalt	29
	Cesium	32
	Chromium	35
	Manganese	35
	Iodine	35
	Observations and Summary	37
	Additional Radionuclide Measurements	37
	Strontium-90	37
	Gross Alpha and Beta Counting	38
	Physical Measurements in Water	41

Page

SECTION V. AQUATIC VEGETATION..... 44

SECTION VI. BENTHIC SEDIMENTS..... 51

SECTION VII. FISH..... 56

SECTION VIII. SUMMARY AND CONCLUSION..... 58

Behavior of Lake Components..... 58
Surveillance Techniques..... 63
Conclusion..... 64

REFERENCES..... 65

APPENDIX I.....A-1

TABLES

1. The distribution of tritium concentration within Lake Robinson..... 31
2. Paired "t" test of tritium concentrations in surface and bottom lake water..... 33
3. Observed concentrations of tritium downstream..... 35
4. Tritium concentrations in wells..... 39
5. Statistical comparison of observed and predicted concentrations of cobalt-58 in Lake Robinson water.... 31
6. Statistical comparison of observed and predicted concentrations of cobalt-60 in Lake Robinson water.... 33
7. Observed and predicted concentrations of radioisotopes of cesium in Lake Robinson..... 34
8. Average chromium-51, manganese-54, and iodine-131 concentrations observed in Lake Robinson water..... 36
9. Gross alpha and beta activity concentrations in Lake Robinson water..... 39
10. Correlation of gross beta determinations with total specific analyses..... 40
11. Average pH and solids content of Lake Robinson water.. 43
12. Average stable element concentration in Lake Robinson water..... 43
13. Aquatic weeds observed in Lake Robinson..... 45
14. Environmental confirmation of radionuclides released in liquid wastes..... 46
15. Radioactive cobalt in Lake Robinson aquatic vegetation 47
16. Radioactive cesium in Lake Robinson aquatic vegetation 48
17. Radioactive iodine and strontium in Lake Robinson aquatic vegetation..... 49

Page

18. Radioactive chromium and manganese in Lake Robinson aquatic vegetation..... 56
19. Radioactivity in Lake Robinson sediments..... 58
20. Radioactivity in Lake Robinson fish..... 59
21. Projected range of equilibrium concentrations at various lake flows..... 60
22. Projected range of doses to an adult swimming 50 hours in expected concentrations..... 61

FIGURES

1. Schematic of H. B. Robinson Unit 2 Power Plant..... 3
2. H. B. Robinson Unit 2 liquid waste disposal system..... 7
3. Geographical location of Lake Robinson..... 9
4. H. B. Robinson site..... 10
5. Important radionuclide pathways to man via surface water..... 11
6. Components of reactor-lake system..... 11
7. Environmental sampling sites in Lake Robinson..... 14
8. Principle dynamic factors reacting within the Lake System..... 17
9. Predicted and observed tritium concentrations in Lake Robinson..... 20
10. Observed and predicted concentrations of cobalt-58 in Lake Robinson..... 20
11. Dredge sampling locations in Lake Robinson..... 53
12. Radioactive cobalt in sediment (position a)..... 54
13. Radioactive cobalt in sediment (position b)..... 54
14. Radioactive cobalt in sediment (position c)..... 54
15. Radioactive cobalt in sediment (position d)..... 55
16. Radioactive cobalt in sediment (position e)..... 55
17. Radioactive cobalt in sediment (position f)..... 55

A-1. Gross power generated (7)..... A-2
A-2. Liquid radioactive waste releases of tritium (7)..... A-2
A-3. Liquid radioactive waste releases - non-tritium (7)... A-3
A-4. Lake Robinson discharge rates (6)..... A-3

ABSTRACT

In the utilization of a cooling lake for a commercial power reactor, low-level quantities of liquid waste are released to the lake water. Due to the retention and recycling of water for condenser cooling purposes, concentrations of radionuclides can increase to levels which are directly measurable in the water. Such a site design is represented by the H. B. Robinson Unit 2 operated by the Carolina Power and Light Company at Hartsville, SC.

For a 4-year period lake water and other lake components such as fish, aquatic vegetation, and benthic sediments were sampled and analyzed to determine if any long-term buildup occurred. Results indicated that the lake water concentrations followed general mixing equations and that turnover rates in the individual components of the lake were too short to quantitate with this study design. This indicates that concentrations of radionuclides in the lake would be primarily a function of parameters such as radioactivity released and lake flow for the previous year and essentially independent of earlier parameters. An estimate of annual external doses to an individual utilizing the lake for recreation (i.e., swimming, boating, and fishing) would be about 6 microrem.

SECTION 1

INTRODUCTION AND OBJECTIVES

Nuclear power plants generate large quantities of radioactive wastes. These wastes are primarily fission products of the fuel and secondarily activation products. The majority of the fission products are retained within the fuel elements until removed during fuel reprocessing. A relatively small quantity of fission products and activation products accumulate in the primary coolant. Most of this radioactive waste is concentrated and removed for off-site shipment and controlled disposal. Small quantities of low-level radioactive wastes which cannot be efficiently processed or contained are released to the environment in liquid and gaseous forms.

Quantities of radioactive wastes released to the environment have generally been much below the 10CFR20 limits established by the U. S. Atomic Energy Commission, currently the Nuclear Regulatory Commission (NRC). More recently, stricter dose and release design objectives have been imposed in the form of Appendix I to 10CFR50 [1]. In general, these design objectives are about a factor of 100 below 10CFR20 [2] limitations and represent a greater compatibility with actual reactor operating experience. With the proliferation of nuclear power, a point of major concern is the long-term buildup in the environment of long-lived radioactive wastes. This buildup will occur when the rate of accumulation exceeds rate of disappearance for a particular radionuclide. Such action increases the concentrations of radioactive waste in one or more compartments or locations of the environment.

Many nuclear power plants utilize large volumes of water to disperse low quality waste heat from their power system. These volumes of water are also conveniently available for dilution of small amounts of radioactive wastes which are considered of such low hazard potential as to be impractical for holding in radioactive waste storage. Dilution further reduces the environmental hazard. A common reactor site design has been to use a river or estuary for water source and disposal. Such a system releases radioactive materials to the environs in such dilute concentrations that positive environmental

measurements are extremely difficult with current analytical techniques.

A second type of siting design is the impoundment of a stream to create a large reservoir. The reservoir acts as both the cooling water source and the receiving water body for the liquid radioactive waste discharges. Water is circulated through the power plant's main condenser and the lake several times before it continues downstream. For this design, concentrations begin to approach the detectable limits of the best analytical methods available. This siting design was chosen in this study to provide data yielding a more definitive determination of radionuclide behavior. The determination can produce a reasonable basis for projecting environmental cost in terms of radiological contamination of the environment.

The particular site chosen for the study is the H. B. Robinson Plant near Hartsville, SC, operated by the Carolina Power and Light Company. The plant consists of a 185 MWe coal-fired unit and a 739 MWe (gross) pressurized light-water reactor unit. The plant uses cooling water from a reservoir formed by a dam on Black Creek. The resultant reservoir interfaces with the larger aquatic system of Black Creek through the creek inflows and the dam overflows. Such limited connections facilitate a demarkation of the system under investigation.

The specific objectives of this study were:

1. To identify and quantitate any long-lived radionuclides released to the environment by the nuclear plant;

2. To determine the concentration of such radionuclides in representative environmental samples of the lake system;

3. To determine the rate of radionuclide buildup within the various components of the lake system;

4. To extend any observed buildup rates through the expected life of the reactor in order to evaluate the impact of the power plant on the general public and the environment.

The study design was based on the approach which was applied to man by the International Commission on Radiation Protection (ICRP) (3). The ICRP described the existing quantity of radioactivity in man as his body burden and then expressed the content within particular organs in terms of fractions of the total body burden. These fractions were then accepted as equilibrium constants and constituted a simple mathematical model which became the basis for various Radiation Concentration Guides. In a lake system it is recognized that these fractions are not constants but dynamic variables which change with time due to external forcing functions. This study was designed to identify and describe the principle forces that govern the transfer and storage of radionuclides in the lake compartments of water, flora, fauna, and benthos. Their actions are formulated in a mathematical expression such that transfer coefficients can be determined for a given set of forcing function parameters such as waste release data and lake flow data. Using time increments of at least a month, erratic day-to-day variations were smoothed to a general trend curve. Thus, a macroscopic analysis rather than a microscopic analysis was chosen which would then supply information directly applicable to a dose-to-man model.

SECTION II

STUDY SITE

Power Plant

The H. B. Robinson electric power generation facility at Hartsville, South Carolina, is owned and operated by the Carolina Power and Light Company. The facility is composed of two units: Unit 1, a 185 MWe fossil fuel plant and Unit 2, a 739 MWe pressurized water reactor. Unit 2 constitutes the entire source term for radioactive materials released in this study. A low power operating license (< 5MWt) was issued July 31, 1970. Initial criticality was achieved September 20, 1970, and authorization to operate the unit at full power (2,300 MWt) was obtained from the AEC on September 23, 1970. H. B. Robinson Unit 2 was declared to be in commercial operation on March 7, 1971 (See Figure A-1, appendix I) (4).

Westinghouse Electric Corporation provided both the Nuclear Steam Supply System (NSSS) and the turbine-generator system. The NSSS includes a pressurized water reactor, the reactor coolant system (RCS), and associated auxiliary fluid systems (Figure 1). Although designed to initially produce 2,300 MWt (710 MWe gross), the power train for H. B. Robinson Unit 2 is expected to be ultimately capable of producing 2,300 MWt.

The reactor core features a typical three-region cycled core. Fuel rods are cold-worked zircaloy tubes containing slightly enriched (1.85 to 3.10 weight percent) uranium dioxide fuel. A total of 79,561 kilograms of uranium dioxide fuel is loaded into the 157 fuel assemblies contained in the core (4).

Three closed but interconnected reactor coolant loops, each containing a reactor coolant pump and a steam generator, comprise the bulk of the reactor coolant system. A pressurizer, a pressurizer relief tank, connective piping, and instrumentation are also provided.

Auxiliary coolant systems include the Residual Heat Removal System (RHRS), the spent fuel pit cooling system, and the component cooling system. The RHRS cools the reactor coolant system during shutdown procedures while the component cooling system cools the reactor coolant

system when shutdown is accomplished. During the power operation the component cooling system cools the reactor coolant system letdown flow to the chemical and volume control system (CVCS) as well as other primary plant components. Other auxiliary fluid systems exist to provide a safety function and plant performance information (sampling systems).

The turbine-generator system is the secondary coolant system and is composed of the shell side of the vertical U-tube steam generators, the turbine generator equipment, two condensers, feedwater apparatus, and associated piping. Steam produced in the steam generators is sent to the turbine-generator to produce electricity. Steam from the turbine is condensed and deaerated at the condenser, heated, and pressurized by the feedwater system, and routed back to the steam generators.

The excess heat of condensation from the secondary coolant loop is transferred to lake water using a heat exchanger as a steam condenser in the coolant loop following the last generating turbine stage. This is accomplished by removing lake water from near the dam, circulating it through a heat exchanger at rates up to 29.7 m³/sec and returning it to the upstream portion of the lake through a 6.7 kilometer cooling canal.

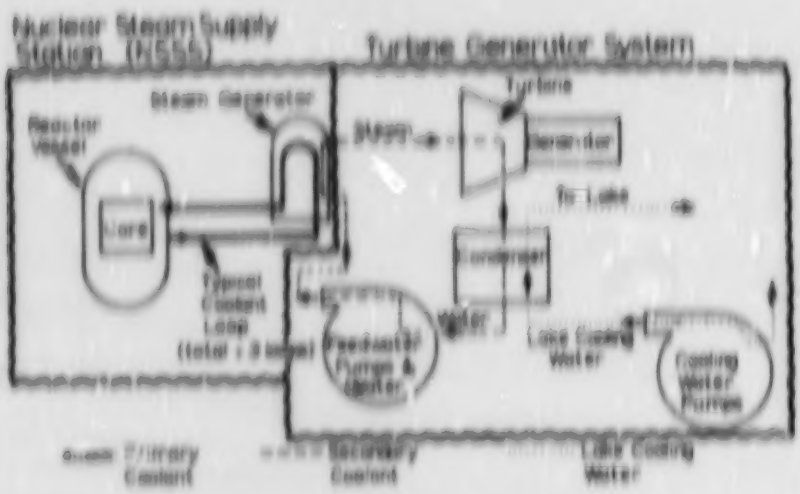


Figure 1. Schematic of H. B. Robinson Unit 2 power plant

Sources of Radioactivity Releases

As fuel burnup occurs fission products increase in the uranium oxide matrix which serves as an initial containment barrier. The zircaloy cladding of the rod provides the next barrier to fission product waste transport. A third barrier to its release is the enclosed primary coolant loop which also provides neutron moderation and heat transfer capability to the power generation loop. The primary coolant loop scavenges much of the fission product leakage and much of the radioactive neutron activation products that become transferrable. The water in this loop also contains a chemical shim, boric acid, to provide for control of the additional reactivity within the core. The primary coolant circulates through the core in three parallel distribution systems, each driving its own steam generator. Decontamination and chemical adjustment controls on the primary coolant are provided by the Chemical Volume Control System (CVCS) which utilizes ion exchange techniques to control and reuse the water as well as to provide make-up water for the primary coolant loops. A single CVCS supplies and maintains the three primary loops. The primary loops operate at about 154.1 bars and are driven by a pump in each loop.

Sources of liquid waste occur as minor and major leaks develop in seals, flanges, and other necessary and inadvertent openings. Shutdown, opening, and repair of the system and its supportive equipment, also provide a mechanism for release of liquid radioactive waste. Equipment leakage is collected in the reactor coolant drain tank and is usually routed to the boron recovery subsystem of the CVCS. Liquids from the CVCS holdup tanks are pumped through ion exchangers (for lithium, cesium, molybdenum, and yttrium removal), a filter, and the gas stripper. Degassed liquid from the gas stripper is then evaporated in the boric acid evaporator condensate demineralizer and filter, and accumulated in the CVCS monitor tanks. This liquid may then be sent to the primary water storage tank for reuse, to the evaporator condensate demineralizers for the CVCS holdup tanks for further treatment, or it may be discharged. Miscellaneous leakages are collected in the containment sump and usually routed to the waste holdup tank in the liquid waste disposal system (figure 2). These leakages amount to only a few liters per minute (4).

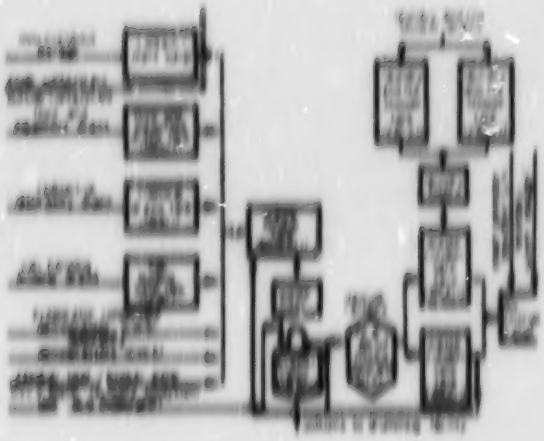


Figure 2. H. B. Robinson Unit 2 liquid waste disposal system

The secondary coolant loop which is a water-to-steam loop contains lesser quantities of radioactivity than the primary loop. This radioactivity is the result of inadvertent leakage across the barrier between the primary and secondary systems. The secondary loop contains 333,900 liters of water at 2200 MWt operation. Since the water chemistry in the secondary loop is closely controlled in a manner similar to that of the primary loop, a continual amount is removed. Although the concentration of these radioactive wastes may be less than that of liquids from the primary coolant, the larger volumes may make this release significant. There are other miscellaneous liquid radioactive waste sources. These are collectively summarized in figure 2 and include additional locations such as radioactive laboratory drains, fuel handling building drains, and laundry and hot shower drains. All of these sources can be fed into the liquid waste disposal system.

Lake Robinson

Lake Robinson is an impoundment of Black Creek completed by Carolina Power and Light Company in 1957 to provide a source of cooling water for the H. B. Robinson power production facilities. The impoundment is located in the southern sand hills region of northern South Carolina and detains water from a watershed of 443 square kilometers.

The lake has a north-south orientation with the dam located at the southern end of the impoundment. The 911 hectare lake contains about 1.8 x 10^7 m^3 of water. This volume is considered constant since its variations are generally less than 20 percent, or well within the experimental error of this study. Forced evaporation due to the thermal loading on the lake effects loss of water at rates of .4 to .6 m^3 per second. Water discharge varies seasonally relative to rainfall. The average discharge rate is 6.8 m^3 per second, but this varies daily from low rates of .74 m^3 per second to higher rates of 31 m^3 per second (5). This varying discharge rate is a major parameter in the radionuclide budget of the lake (see figure A-8 of appendix I). The discharge flows into a smaller impoundment, Prestwood Lake, about 8 kilometers downstream. Prestwood Lake supplies water to several industrial users for manufacturing processes. Neither Prestwood lake nor downstream Black Creek is used as a supply of drinking water.

Lake Robinson was constructed on land which contained primarily second growth pines, bottom lands, swamp, and some hardwoods. The shoreline consists of grasses, pine seedlings and granite fill used for erosion control. The lake is approximately 12 kilometers long from north to south with a mean width of .8 kilometers.

The lake has a basin 12 to 18 meters deep at the southern end near the dam. The old creek bed forms a twisting channel 6 to 8 meters deep near the basin but only 3 to 4 meters deep near the bridge at the upper end of the lake. On either side of the channel lie extensive "shallow" flats which cover significant areas with depths of 1 to 2 meters. North of the bridge the area is flooded hardwood land with a treacherous bottom littered with decaying debris such as stumps and dead trees. The freshwater of Black Creek passes through several bogs or marshland areas acquiring the "brown water" coloration from the humic acids of these areas.

Lake Robinson, therefore, has attained the characteristics of a "bog lake" or "brown water" lake as described by Huttner (5). Such characteristics include low nutrients, low pH, and high discoloration. The biological productivity of the lake could, therefore, be predicted as being relatively low.

Lake Robinson is available to the general public and is used for recreational purposes such as boating, water skiing, sport fishing, and swimming. Numerous private residences have been built on the eastern shore of the lake. Figure 3 and figure 4 present the location and the arrangement of lake, stream flow, and reactor.

Figure 3. Geographical location of Lake Robinson

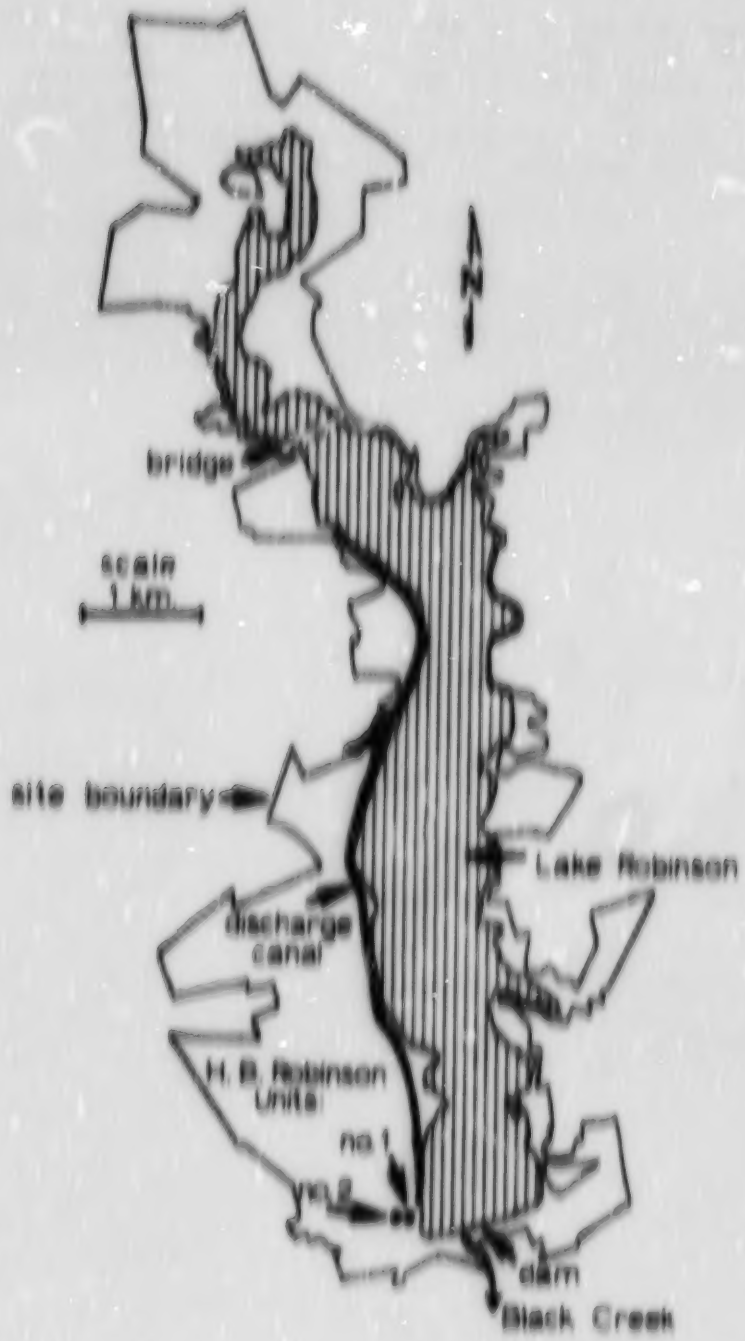


Figure 4. H. B. Robinson site

SECTION III

STUDY METHODOLOGY

Study Design

The approach to this study began with a generalized model or grouping of the components of the lake system and the dominant environmental factors interacting with the system. Figure 5 represents the important radionuclide pathways to man selected as the bases for the design of this study. The model is applicable to liquid releases to most aquatic ecosystems. Figure 6 depicts the salient relations of this particular system. From such a grouping the study design was developed to either measure or infer through simulation, the significance of each particular interaction or component storage. The stepwise approach was to use observed data to guide subsequent alterations in the study design so that system characterization would emerge as the research progressed. An example of this was the utilization of tritium data to verify physical attributes of the lake such as lake volume and mixing properties.

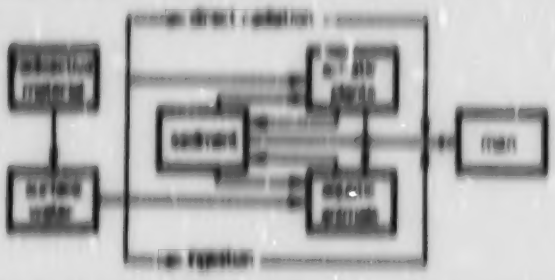


Figure 5. Important radionuclide pathways to man via surface water

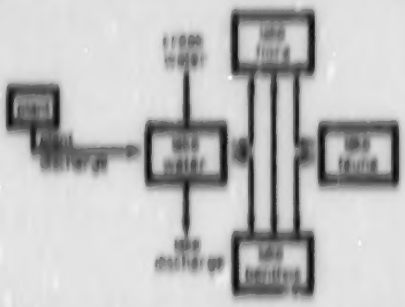


Figure 6. Components of reactor-lake system

Lake-flow data from the United States Department of Interior (6), physical parameters used in the environmental evaluations by the Carolina Power and Light Company (4), effluent release data, and other operating data as reported by the Company (7) were used to develop a dynamic picture of the system. This dynamic picture was evaluated by a series of 10 surveys spaced over a 4-year period. Thus, the effort was similar to taking a series of 10 in-depth, still photographs over a 4-year period to represent a complex, dynamic system in motion on a macroscopic scale. The intent was to determine content of radioactive pollutants within the components represented in Figure 6 and observe the effect of flows or transport between the components.

Lake Survey

Lake Robinson represents the focal point of this study. In order to acquire an adequate radiological "portrait" of the lake, an in-depth field survey protocol was developed. Each element of the survey was chosen to provide data on the radionuclide content of an ecosystem component and associated parameters which might monitor physical and biological actions within the system. The sampling strategy was to collect numerous small volume samples for radionuclide analysis of readily detectable nuclides and fewer but larger volume samples for radionuclides which occurred in smaller concentrations and were more difficult to detect. The analytical data was correlated with analyses of reactor waste streams and lake flows. The surveys were spaced from 3 to 6 months apart to provide adequate time increments such that measurable changes could occur.

Sampling

The sampling protocol was directed towards determining the radionuclide content of the water, benthic soil and sediments, aquatic flora, and aquatic fauna. The primary effort was to sample for positive indications of radioactivity. To implement the protocol, a team of at least four EPA field survey members was required, along with the assistance of Carolina Power and Light Company personnel and two technicians from the South Carolina Department of Health and Environmental Control, Bureau of Radiological Health. The surveys were conducted on 3 successive days and required the use of a specially equipped 4.3 meter outboard motor boat and a varied quan-

tity of sampling equipment and operational gear. In the course of each sampling trip, approximately 100 environmental and in-plant samples were taken. The sampling program required that not only the lake itself be accurately represented, but also that effects downstream be identified, transport to the underlying aquifer be evaluated, and background radioactivity data be obtained either from points upstream and unaffected by the reactor or from a nearby lake of similar nature, also unaffected by the reactor.

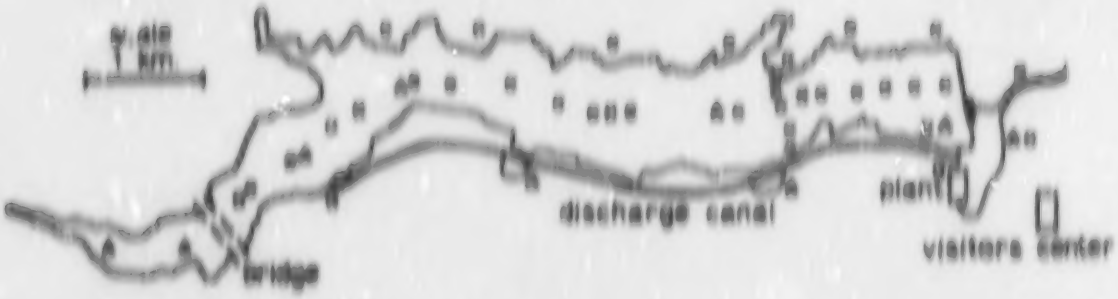
The major emphasis in the survey was the evaluation of the lake water itself. To accomplish this, three sampling systems were established to provide for varying required sensitivities for the different radionuclides and for better determination of physical distribution about the lake.

The first system was established for analyzing tritium in the lake water. Since it was expected that tritium concentrations would exceed the minimum detectable limits of .2 nCi/liter after the reactor had operated for about 9 months (8) a simplified analytical method could be used. This permitted the analyses of a large number of samples. The system for tritium samples consisted of 33 lake sampling locations. Nineteen of these locations were on the center line of the lake beginning at the dam and extending upLake with a separation of about .5 kilometer. Four sites were located on a cross section line of the lake at the eighth site north of the dam or about 2.7 kilometers. This provided five locations evenly spaced across the lake from shore to shore. At each location two 1-liter samples were drawn, one near the surface and one just above the bottom (approximately .5 meter). In addition to determining tritium concentrations, this system was designed to provide information relative to lake mixing and lake volume. The 1-liter sample size was chosen to provide adequate quantity of samples for replicate analyses. The normal analytical procedure required 100 milliliters of water per analysis.

The second water sampling system consisted of eight sampling sites up the center of the lake. The sample size for this set was 10 liters. The samples were drawn from 1 to 2 meters deep. The sites began at the dam with three in the lower lake area at .8 kilometer intervals and five in the upper lake area at .8 kilometer intervals, one centerlake opposite the mouth of the discharge

canal, two north of that point, and two south of that point. This sample set provided measurements at an intermediate level of sensitivity for all gamma emitting radionuclides as well as strontium-89, strontium-90, pH, stable elements, and dissolved and undissolved solids.

A third sampling system was established to provide maximum feasible sensitivity of measurement of gamma emitting radionuclides in the water by using a sample volume of 200 liters. These sampling sites were: two in the lake center .8 kilometers above and below the mouth of the discharge canal, two in the lower lake .8 kilometers and 2.4 kilometers north of the dam at the lake center, one at the cooling water intake, one at the cooling water discharge to the canal and one at the mouth of the discharge canal. A background sample of this size was also taken. This was initially drawn from Black Creek at the U. S. 1 highway bridge. Later it was decided to move the background sampling point to Beaverdam Millpond. This small lake had chemical characterization similar to Lake Robinson, but received no surface drainage from the H. B. Robinson Unit 2 (See Figure 7 on sampling locations).



legend

B : 200 liters of water for resin cartridge

B : 1 liter of water for tritium analysis

A : 10 liters of water, sediment,

vegetation is collected where available in lake

Figure 7. Environmental sampling sites in Lake Robinson

Benthic soils or silt samples were collected with a Peterson dredge at the eight locations selected for the 19-liter water sample system. The dredge "bite" represents .078 m^2. A single sample represented two bites or .156 m^2. The sample was dried, weighed, and analyzed by gamma spectroscopy (gamma scanned).

Aquatic vegetation was collected in the littoral areas as near as possible to the eight locations selected for 19-liter water samples and benthic soil samples. The priority of choice of vegetation was submerged weeds, floating weeds, and emergent weeds. Of the submerged weeds, Myriophylum was one of the available species and Najas flexilis was another. Of the floating weeds, Dracenia was most commonly selected. Assistance in plant identifications was provided by the Biological Services Branch of the EPA Environmental Research Laboratory, Athens, Georgia. These were washed, drain-dried, weighed, gamma scanned, ashed, weighed, and gamma scanned for the second time.

Fish samples were supplied by the South Carolina State Wildlife Department and South Carolina Department of Health and Environmental Control personnel who used electrical shocking to collect fish. Because of the techniques employed and because of a low population of fish, significant sample sizes were not available to correspond with each field trip. When fish were available, they were separated into sets of species, each set being counted separately. Large individual fish and large numbers of single species were separated into viscera, bone, and flesh; then, analyzed.

At the inception of the study, the power plant reported liquid releases in curies of tritium and "non-tritium" on a monthly basis. This hampered isotopic evaluation; therefore, with the assistance of Carolina Power and Light, liquid waste samples, proportioned to the quantity released, were collected and analyzed to estimate isotopic releases. By July 1972, Carolina Power and Light Company began reporting specific radionuclide releases. After an overlap of procedures demonstrated close agreement between composite release estimates and the power plant's reported releases, the composite system was dropped in January 1973.

Other in-plant systems were sampled in order to provide a potential insight as to the sources of liquid

wastes within the plant. This included samples from available sampling points in the primary coolant, CVCS, secondary system, and other miscellaneous systems such as the component cooling water system. Information at these points gave a more complete picture of the extent and significance of these systems in total liquid releases. All in-plant samples were taken by plant personnel in accordance with their established procedures, with sample size determined by expected concentrations and available sample quantity.

In addition to these major sampling procedures, several peripheral programs were implemented to provide information connecting the lake system, the reactor, and the surrounding environment. One such effort was the sampling of 16 private drinking water wells at residences bordering the lake. One-liter samples were taken for tritium analyses to detect any significant transport from the lake to the water supplying aquifer. Additional sampling was initiated downstream on Black Creek to determine the dilution and dispersion as the flow travels downstream. Midway through the study, Carolina Power and Light Company suggested that a drainage ditch leading from the reactor directly to a point below the dam should be monitored. Subsequently, water and vegetation in this ditch were sampled when available. The effects of flow down the cooling canal and through two side pools on the cooling canal were also monitored. Water, sediments, and littoral vegetation were sampled at this location.

SECTION IV

WATER

Lake Model

The simplest description of the turnover of radioactivity in the lake is one derived from the major physical aspects of the lake system. The model is similar to a continued insertion of a radionuclide into a tank with an inflow and a discharge rate. Figure 8 represents this in block diagram form.

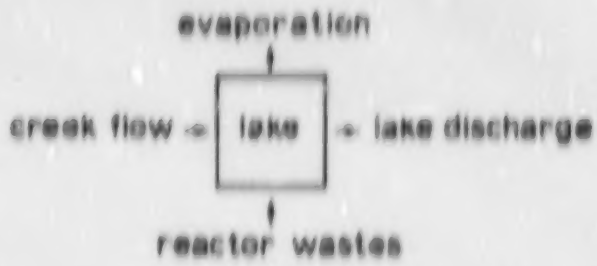


Figure 8. Principle dynamic factors reacting within the Lake System

The mathematical expression for the change in radioactivity in this lake would be as follows:

$$\frac{dA}{dt} = P - \frac{Q_{evap}A}{V} - \frac{Q_{flow}A}{V} - \lambda A$$

Where:

$\frac{dA}{dt}$ = Rate of change of radioactivity in the lake

A = Radioactivity in the lake

P = Rate radioactivity is added to the lake

Q_{flow} = Rate of water discharged from lake

Q_{evap} = Rate of evaporation from the lake

λ_i = The radionuclide decay constant

V = Lake volume

In order to reduce the expression to a more manageable form the effective removal rate is defined as:

$$\lambda_{eff} = \frac{Q_{flow}}{V} + \frac{Q_{evap}}{V} + \lambda_i$$

Thus the differential equation is expressed as:

(Equation 1)

$$\frac{dA}{dt} = -\lambda_{eff,i} A$$

This equation integrated becomes:

$$A_i = \frac{P}{\lambda_{eff,i}} (1 - e^{-\lambda_{eff,i} t}) + A_0 e^{-\lambda_{eff,i} t}$$

A_0 = Radioactivity in the lake at the beginning of time period "t"

A_i = Radioactivity of radionuclide "i" in the lake at the end of the period

Expressing this in terms of concentration of an "i" radionuclide, the equation becomes:

(Equation 2)

$$C_i = \frac{P_i}{V\lambda_{eff,i}} (1-e^{-\lambda_{eff,i} t}) + C_0 e^{-\lambda_{eff,i} t}$$

It should be observed that the equation and its application implies several assumptions:

1. The lake volume is assumed constant. This assumption seems reasonably valid based on lake data (9) which shows the lake level has a limited variation. The value used was 3.8×10^7 m^3.

2. The radionuclide release rate is constant throughout the period of concern. This was a necessary assumption due to the lack of records on times, dates, and quantities of releases. The official records show total releases for the month and do not detail when specific releases occurred. In general these releases were of sufficient number and quantity to be reasonably approximated by the constant rate assumption.

3. Rapid mixing occurs in the lake to establish uniform concentrations. This is not an unreasonable assumption since the cooling water pumps move the lake water at 29.7 m^3/sec through the main condensers and down the discharge canal as compared to an average lake discharge of 4.8 m^3/sec.

4. The loss or removal from the lake by evaporative transport was applicable to tritium only. For other radionuclides this did not constitute a significant radionuclide transport mode and was, therefore, neglected.

5. There is no other significant storage or escape route from the lake water. This assumption is apparently valid for tritium; however, possible departures for other radionuclides will be discussed later.

Evaluation of the Model for Tritium

Tritium appeared to be a natural tracer for the evaluation of the water turnover model represented by equation 2. The primary form of the tritium was HTO and, therefore, the tracer behaved chemically and physically like water. Additionally, liquid releases would be expected to be in sufficient quantities that the resultant concentration in the lake could be easily measured by sufficiently simple analytical procedures so that numerous samples could be processed to provide a solid broad data base and increase power of the statistical tests.

The model is compared to the observed lake values over the 4-year period to observe the correlation between the predicted and observed values. Figure 3 shows a comparison of observed and calculated values for the duration of the study.

The calculated values were determined using the release rates reported by the company in their operating reports (7) for the respective month and an initial concentration as calculated for the end of the previous month. The flow data was that provided by the United States Department of the Interior, Geological Survey, in Columbia, SC, for the gaging station #02130910 located 305 meters below the Lake Robinson dam (8). The mean monthly flow observed for the specific month in question was

used. The concentration was determined from the selected month's data and plotted as the concentration in the lake existing on the first day of the next month.

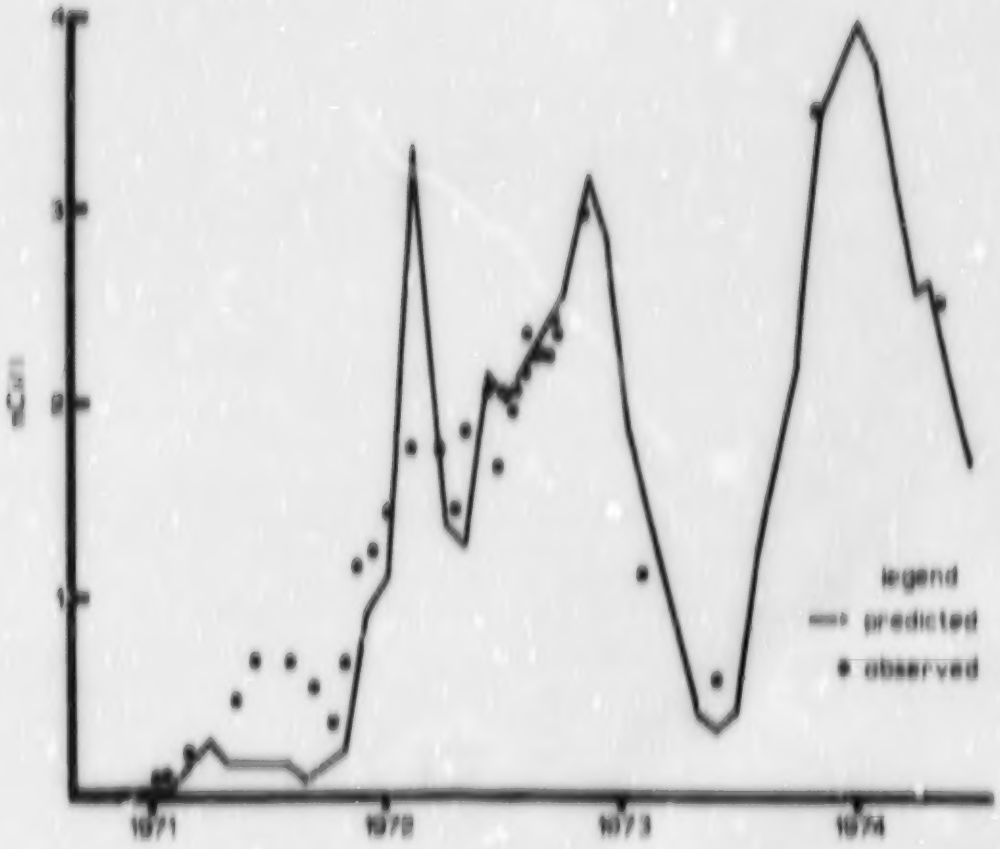


Figure 9. Predicted and observed tritium concentrations in Lake Robinson

Table 1

The distribution of tritium concentration within Lake Robinson

nCi/l

Trip Date	No. of Samples	Mean	Max	Min	S.E.	Analytical Range	Percent Observations in Analytical Range
I 12/01/70	46	<.2	<.2	<.2		± .2	100
II 03/09/71	46	.28	.4	<.2	.11	± .2	100
III 06/21/71	46	.47	.6	.3	.08	± .2	100
IV 03/14/72	43	1.69	1.9	1.1	.14	± .2	91
V 07/10/72	41	2.18	2.5	1.1	.22	± .2	93
VI 10/31/72	50	3.05	3.4	1.6	.33	± .2	72
VII 02/06/73	41	1.15	1.4	.4	.28	± .2	78
VIII 06/05/73	43	.61	.9	.4	.10	± .2	95
IX 11/05/73	43	3.70	4.8	2.9	.37	± .3	88
X 05/14/74	43	2.65	2.9	2.2	.14	± .2	88

Two sections of the figure show significant disagreement between the observed and predicted values. The period of May-to-September of 1971 shows observed concentrations from .5 to .7 nCi/liter as compared to predicted values of about .2 nCi/liter. These observed values represent duplicate analytical runs on separate dates. Unless contamination of the sample occurred in the field, there is strong indication that they are correct. During the time period from May 29 to August 20, 1971, the reactor was shut down for extensive generator repairs as well as for other numerous maintenance operations. It might be reasonable to suspect that recorded releases were in error. Another plausible explanation is that extensive stratification was occurring due to the reduced operation of the circulating cooling water pumps during the shutdown. Such reduction undoubtedly would affect the lake mixing action and consequently reduce the effective mixing volume of the lake. Consequently, the observed concentration would appear higher than expected. This effect, however, would show a faster turnover rate which was not apparent.

A second significant discrepancy occurred in February 1972 where predicted concentrations reached 3.4 nCi/liter and observed concentrations reached about 1.8 nCi/liter. It is believed that this is a question of timing of releases and the month-grouping method of handling the data. Thus, the peaking described by the model could have occurred between or prior to the two 1.8 nanocurie samples.

Aside from the aforementioned sections of the study, the predicted and observed concentration values demonstrate excellent agreement. Such agreement seems to recommend the acceptance of the model and its parameters as a valid simulator of the water behavior of the lake. This infers that the stated assumptions are likely valid.

The assumption of adequate lake mixing seemed to require further evaluation. Table 1 summarizes the observed data for tritium showing the number of observations, the mean, maximum, and minimum values, the standard deviation, and the percent of the observations contained within the range of the mean plus and minus the stated analytical error. From

this table it should be noted that the data points are well clustered about the mean within the range of the analytical error.

In an effort to test the effect of stratification of water, a paired "t" test was used to test the hypothesis that surface water samples had values from the same sample population as water samples taken near the bottom of the same lake location. The test was a two-tailed test at the 95 percent confidence level. Multiple "t" tests are summarized in table 2. Nine trips had sufficient positive data to analyze.

Table 2

Paired "t" test of tritium concentrations in surface and bottom lake water

n = 179 pairs

$\bar{D}$ = 0.067 nCi/liter

S_D = 0.284

α = .05

Degrees of Freedom = 178

Ho: Surface Conc. - Bottom Conc. = 0

Test Statistic

$$t = \frac{0.067}{0.284} (178)^{\frac{1}{2}} = 3.15$$

$t_{(\alpha/2)} = t\ (.025) = 1.96 < 3.15$ Ho: rejected

Alt Ho: Surface Conc. > Bottom Conc.

Alt Ho: Accepted

The test used 179 pairs of observations which indicated that tritium concentration in surface water exceeded that of deep water an average of .067 nCi/liter. The sample standard deviation (SD) = .288, degrees of freedom = 178, and the test statistic "t" = 3.15. Since 3.15 is greater than 1.96, the hypothesis that the difference was zero, was rejected and the alternate hypothesis that the difference was greater than zero was accepted. Such a hypothesis indicates that some physical stratification does take place as the lake receives the small amounts of radioactivity mixed with water which is at a temperature elevated above ambient lake temperatures. In general, it is important to note the magnitude of this stratification. In this particular test the average concentration was 1.75 nCi/liter, and the average observed difference was .067 nCi/liter or less than 4 percent of the average observed concentration. The difference is about one-third of the minimum detectable concentration for tritium of .2 nCi/liter. The treatment of the lake by the model as a mixed lake should not introduce an error greater than the errors introduced by sampling and analysis and thus the mixed lake assumption is realistic for the purposes for which it was intended.

This comparison seems to verify the model as a plausible description of dilution within the range of analytical error. It is, therefore, concluded from these comparisons that equation 2 adequately describes the water mixing properties of the lake within the overall measurement error of the study and that the constant lake volume of 3.8×10^7 m^3 is a valid assumption. It is also concluded that the mixing of the water is sufficiently effective to support the uniform mixing assumption over time periods of weeks or greater. A subsequent inference is that long-term buildup of the "i" radionuclide in the water based on the model would reach an equilibrium or "steady state" value given by:

(Equation 3)

$$C_{equilibrium} = \frac{P_i}{\lambda_{eff,i}}$$

The highest release rate of tritium reported during this study was for December 1973 at 79.24 Ci/mo. Such a release rate would result in concentrations from .8 nCi/liter to 4.8 nCi/liter depending on the lake discharge rate. The highest concentration observed from a single sample in the lake was 4.8 nCi/liter on November 6, 1973. This is .16percent of 10CFR20 (2), guideline for radioactive "effluents to unrestricted areas." The highest tritium concentration representative of the lake was 3.7 nCi/liter or .1 percent of Appendix B guideline (2). Thus the radioactive waste concentration buildup is controlled by lake flow, radioactive decay rate, and the discharge rate of the radioactive pollutant. For long-lived radioisotopes with half-lives of greater than a year, the lake flow rate is the dominating factor which affects buildup for a given radioactive discharge rate. Data from October 1966 to September 1974 on the average monthly lake flow shows that this parameter might vary from 2.27 m^3/sec to 13.65 m^3/sec causing the "half-life" time of a particle of water to vary from 23 days to 136 days. Thus the maximum buildup of a long-lived radionuclide could be determined by:

(Equation 4)

$$C_{max} = \frac{P_i}{Q}$$

Where:

P_i = Release rate of nuclide "i"

Q = Lake flow rate

Downstream Dilution of Tritium

Because the tritium concentrations were well above detectable levels, it was decided that an evaluation of the rate of dilution downstream on Black Creek was desirable. On Trips VIII, IX, and X five points were sampled at 3.2, 6, 25, 32.7, and 44 kilometers downstream. These locations were at the bridge of Highway 39 (3.2 kilometers), pier at the end of Churchill Street in Hartsville, SC, (6 kilometers), the bridge of Highway 52 (25 kilometers), the bridge of Highway 151 (32.7 kilometers), and the bridge of Highway 35 (44 kilometers). The last point is about one kilometer above the confluence of Black Creek and the Pee Dee River. The tritium concentration values are given in table 3.

Table 3

Observed concentrations of tritium downstream

nCi/l

Position	Distance (km)	Trip VIII	Trip IX	Trip X
At the dam	0	.6 ± .2	3.7 ± .2	3.7 ± .2
HW 39	3.2	.6 ± .2	4.1 ± .2	3.7 ± .2
Churchill St.	6	.5 ± .2	2.9 ± .2	3.4 ± .2
HW 52	25	.4 ± .2	1.6 ± .2	1.7 ± .2
HW 151	32.7	.5 ± .2	1.8 ± .2	1.6 ± .2
HW 73	44	.5 ± .2	1.3 ± .2	1.4 ± .2

Since the Trip VIII data seemed to show no trend due to its large fractional error, the trip data for IX and X were used to determine an exponential curve of the form:

$$y = ae^{bx}$$

This yielded the constant values of:

Trip IX	Trip X
a = 3.7	a = 3.7
b = -.025	b = -.016

It is significant to note that the coefficients of determination for Trips IX and X are r = .91 and .98, respectively. This indicates a relatively high degree of correlation. The resultant implied model for downstream dilution is:

(Equation 5)

$$C = C_L e^{-.02x}$$

C = concentration of nuclide downstream at "x" kilometers below the dam

C_L = average concentration of nuclide in the lake

x = kilometers downstream of dam (not to exceed 65 kilometers)

Tritium in Well Water

Tritium concentrations were also determined in water samples from wells surrounding the lake to monitor the significance of transport from the lake to the underlying aquifers. The results of this study summarized in table 4 are basically inconclusive. Even though an enrichment procedure was used to increase the sensitivity of the analytical procedure on a selected group of these samples there seemed to be no significant correlation between the average of the well water samples and the average lake concentration; hence no quantitative estimate could be made of any transport coefficient from the lake to the aquifers. Neither could one say conclusively that such transfer does not occur.

Gamma Emitting Radionuclides

From the liquid waste releases of the reactor there are several radionuclides which are gamma emitters, a characteristic which simplifies their detection and analysis. Many of these radionuclides are isotopes of elements useful to biological systems and are therefore reconcentrated within the biological components of the lake system. Others have chemical forms which react with components of the environment so as to effect reconcentration or dissolution through ion exchange, molecular complexing, and other physical interactions. Many radioisotopes are subject to both physical and biological forces. In order to assess the significance of these forces the lake water concentration must be determined or inferred. It is important in this study that not only the concentration observed during a field trip be accurate but some estimate of concentrations with time between trips be available.

Cobalt

Radioisotopes of cobalt are of particular interest. These are produced by neutron activation within the hardware of the reactor core. During Trip 1 the concentration of cobalt-58 was readily measurable in the lake water. On subsequent trips cobalt-60 concentrations were measurable using the large volume sample data. Figure 10 shows observed concentrations of cobalt-58 as compared to concentrations predicted by equation 2 and using release

Table 4

Tritium concentrations in wells

nCi/l

Well	Trip IV 03/14/74	Trip VII 01/06/73	Trip VIII 08/08/73	Trip IX 11/08/74	Trip X 05/14/74
33-A	.15*	.13*	<.2	< .2	.10*
39-A	.4	.3	.2	.3	.3
39-B	.24	.2	.2	.4	.2
595-A	.10	.01	<.2	< .2	.10
737-A	.10	.13	<.2	< .2	.4
737-B	.41	.4	.2	.3	.2
574	<.2	.04	<.2	.2	.10
Trailer	.3	NS	.4	.4	NS
House on E. Shore	.3	NS	NS	NS	NS
Avg.	.24	.17	<.2	.24	.17
S_D	.12	.14	-	-	.08
Lake Avg.	1.69	1.15	.61	1.7	2.65

NS - No sample.
* Data reported to the nearest hundredth was determined by a tritium enrichment procedure.

data as available from reactor operating records. The triangles enclosed in a square indicate that the value was less than detectable and is plotted at .025 pCi/liter or one-fourth the normal minimum detectable limits. In order to evaluate the comparison of observed versus expected values a paired "t" test was run to determine if the means of the two sample populations were significantly different. This is represented in table 5. As shown in the table the means were not statistically different. Thus the model is a reasonable estimate of the observed lake concentration of cobalt even though its correlation to observed data is not as close as for tritium.

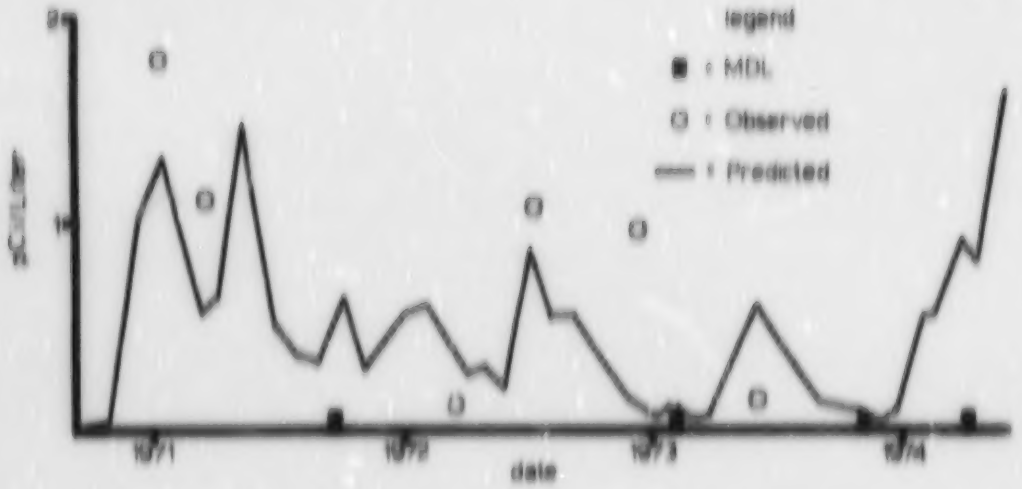


Figure 10. Observed and predicted concentrations of cobalt-58 in Lake Robinson

Table 5

Statistical comparison of observed and predicted concentrations of cobalt-58 in Lake Robinson water

pCi/l

Trip	Date	Observed	Predicted
I	12/01/70	1.78	1.0
II	03/09/71	1.10	.56
III	09/21/71	ND	.66
IV	03/14/72	.12	.36
V	07/10/72	1.07	.79
VI	10/31/72	.96	.10
VII	03/06/73	.03	.11
VIII	06/05/73	.14	.56
IX	11/05/73	ND	.1
X	05/14/74	ND	.85

H_0: observed − estimated = 0

$t_{.025} = \pm 2.262$

Confidence Level = 1−α = 95%

$-2.262 < .095 < 2.262$

H_0 accepted

$\bar{D} = .0175$

$s_{\bar{D}} = .5818$

$t = .095$

$df = 9$

ND = Not detected.

From both the model and the observed data we see that measurable concentrations were likely in two periods: November 1970 to July 1971 and June 1972 to November 1972. A third rise was predicted by the model from May 1973 to July 1974, but this was not verified by the observations.

A similar comparison was made using observed and predicted values of cobalt-60. This is presented in table 6. In this case the poor fit becomes more evident as the difference between the observed and predicted is shown to be statistically significant. Furthermore, the test indicates that the mean of the estimated values is greater than that of the observed values. This would support use of the model as an upper limit estimator of lake concentration trends.

Cesium

Another element having radioisotopes which occurred in detectable concentrations in the water was cesium. Cesium-137 and cesium-134 are generated in the fission process as opposed to the activation production of most of the other gamma emitting radionuclides. Thus, the appearance of these isotopes occurs as a result of leaking fuel elements and subsequent containment leakages unrelated to the activation product releases in the liquid wastes.

Cesium-137 is a primary radionuclide in worldwide fallout and is present in small quantities in the general environment. The mean value for the concentration of cesium-137 in the water prior to any reactor influence is estimated as .11 pCi/liter. This value was determined, based on the average of all background water analyses performed from all the trips. Table 7 summarizes the cesium data for both cesium-137 and cesium-134. The predicted value for cesium-137 is calculated by adding the background value to the value calculated by equation 2. The standard deviation is not calculated when the number of values averaged is less than four. The good agreement between observed and predicted values is due mainly to the small contribution from reactor releases as compared to background values. As releases became more significant, the divergence between observed and predicted concentrations occurs. Table 7 summarizes and compares observed and predicted values for cesium.

Table 6

Statistical comparison of observed and predicted concentrations of cobalt-60 in Lake Robinson water pCi/l

Trip	Date	Observed	Predicted
I	12/01/70	.1	.025
II	03/09/71	.2	.25
III	09/21/71	ND	.74
IV	03/14/72	.1	1.4
V	07/10/72	.1	1.3
VI	10/31/72	.09	.8
VII	03/06/73	.05	.52
VIII	06/05/73	.06	.55
IX	11/05/73	ND	.56
X	05/14/74	ND	1.65

Ho: observed - estimated = 0

$t_{.025} = \pm 2.262$

Confidence level = 1-α = 95%

-3.80 < -2.262

Ho: rejected

$\bar{D} = -.68$

$s_D = .57$

$t = -3.80$

$df = 9$

ND = Not detected.

Table 7

Observed and predicted concentrations of radioisotopes of cesium in Lake Robinson

pCi/l

Trip Date	Cesium-137 Observed (Standard Deviation)	Cesium-137 Predicted	Cesium-134 Observed (Standard Deviation)	Cesium-134 Predicted
I 12/01/70	.2 (*)	.11	ND	ND
II 03/09/71	.2 (*)	.11	ND	ND
III 09/21/71	.22 (.11)	.11	ND	ND
IV 03/14/72	.11 (.03)	.11	ND	ND
V 07/10/72	.18 (.06)	.16	ND	.04
VI 10/31/72	.16 (.03)	.16	.02 (.05)	.04
VII 03/06/73	.15 (.06)	.15	ND	.06
VIII 06/05/73	.24 (.04)	.76	.14 (.04)	.24
IX 11/05/73	.19 (.04)	.45	.03 (.04)	.09
X 05/14/74	3.2 (.5)	1.45	2.4 (.7)	1.2
Background	.11 (.05)		ND	

*Insufficient number of data points to estimate standard deviations, (< 4)

ND = Not detected.

Chromium

Chromium-51, an activation product, was observed in water at concentrations from 1 to 2 pCi/liter during three of the sampling periods. The summary of this data is shown in table 8. Predicted values using equation 3 never exceeded .16 pCi/liter.

Manganese

The detection of the activation product, manganese-54, was inconclusive because of complications in interpreting the interference of manganese-54 with a .83 MeV gamma with the .81 MeV gamma energy of cobalt-58. In most cases positive analysis of these two could only be accomplished following chemical separation prior to gamma spectral analysis or utilization of a Ge(Li) counting system. This factor reduced the sensitivity of the detection and, consequently increased the minimum detectable concentration to apparently .2 pCi/liter. It is interesting that the predictive model shows the concentration of manganese-54 to range consistently between .1 and 1.0 pCi/liter. The concentrations of manganese are summarized in table 8.

Iodine

Iodine-131, another fission product, was detected in the final survey at an average concentration of 4.5 pCi/liter. Prediction of iodine-131 concentrations were not attempted due to the short half-life of 8.1 days. This would cause the lake concentration to be highly responsive to the specific time of release and the quantity released. Averaging the total monthly release would introduce an unreasonable error as compared to observed lake concentrations. The May 14, 1974, samples averaged 4.5 pCi/liter with a standard deviation of 1.9 pCi/liter.

Table 8

Average chromium-51, manganese-54
and iodine-131 concentrations
observed in Lake Robinson water
pCi/l

Trip Date	^{51}Cr	^{54}Mn	^{131}I
I 12/01/70	2.2	<.05	<.05
II 03/09/71	<.3	<.05	<.05
III 09/21/71	<.3	<.05	<.05
IV 03/14/72	1.28	<.05	<.05
V 07/10/72	1.60	.15	<.05
VI 10/31/72	<.3	.03	<.05
VII 02/06/73	<.3	<.05	<.05
VIII 06/05/73	<.3	.10	<.05
IX 11/05/73	<.3	<.05	<.05
X 05/14/74	<.3	<.05	4.5

Observations and Summary

The non-tritium data demonstrates an increasing divergence from the predictive model of equation 3. This is likely due to the origin and nature of this waste as compared to tritium. The tritium is not concentrated in the waste evaporators, and each release of liquid waste will contain a quantity of tritium consistent with the tritium inventory which has leaked from the primary coolant loop. Hence, the mathematical treatment of tritium as a continuous rate release is usually quite valid. The non-tritium radionuclides originate from many varied points within the reactor core. This is particularly true of activation products. The physical and chemical forms of these products regulate the effectiveness of the waste evaporator in removing these contaminants from the system. As a result, effective modeling of these contaminants should treat their releases as discreet events as opposed to a continuous steady rate occurrence. The same may be said for fission products which enter various liquid wastes. The reactor operators who have a record of liquid release data could easily maintain a running estimate of radionuclide concentrations in the lake.

Additional Radionuclide Measurements

Strontium-90

Strontium-90 is a fission product which has been released to the earth's biosphere from past nuclear weapons tests and is found in many environmental samples. Due to the radiotoxicity of strontium-90 and its presence in reactor wastes, water samples were analyzed for this radionuclide. A specific chemical separation for strontium was performed on 4-liter aliquots of lake water drawn from the 19-liter sample sets. For survey Trips 1-IX no strontium-90 or strontium-89 was detected. Of the eight water samples analyzed, for survey Trip X, four indicated less than the detectable limits of .25 pCi/liter. The other four indicated an average of .27 pCi/liter of strontium-90 and a standard deviation of .017 pCi/liter. Since the minimum detectable limit was determined to be .25 pCi/liter, it was concluded that the lake concentration was likely less than the .25 pCi/liter detection limit for strontium-90. No strontium-89 was detected in any lake water samples.

Gross Alpha and Beta Counting

Environmental radioactivity monitoring programs have historically reported gross alpha and beta counts to serve as a trend indicator of radioactivity in environmental samples. In order to provide comparison data in this format, Table 9 summarizes results of the current Lake Robinson survey.

The gross beta data were tested for correlation with the total of the non-tritium activity in the water. This comparison is summarized in Table 10. A linear regression fit was determined using the dissolved solids gross beta average as the independent variable (x) and the sum of the non-tritium average activity data as the dependent variable (y). The resultant equation was:

$$y = -1.43 + 1.0x$$

Where:

y = Total non-tritium concentration (pCi/liter)

x = Observed gross beta in dissolved solids (pCi/liter)

The coefficient of determination (.59) demonstrates that the gross beta data were of limited value for estimating concentrations of non-tritium activity in the water.

Table 9

Gross alpha and beta activity concentrations
in Lake Robinson water
pCi/l

Trip Date	Undissolved Solids Beta	Undissolved Solids Alpha	Dissolved Solids Beta	Dissolved Solids Alpha
I 12/01/70	< 1	< 2	2.4 ± 1.8*	< 2
II 03/09/71	< 1	< 2	3.4 ± .64	< 2
III 09/21/71	< 1	< 2	2.7 ± .38	< 2
IV 03/14/72	< 1	< 2	1.1 ± .70	< 2
V 07/10/72	1.3 ± 1.9	< 2	1.75 ± .83	< 2
VI 10/31/72	< 1	< 2	1.3 ± .62	< 2
VII 03/06/73	< 1	< 2	1.44 ± .69	< 2
VIII 06/05/73	< 1	< 2	.9 ± 1.1	< 2
IX 11/05/73	< 1	< 2	.89 ± .98	< 2
X 05/14/74	1.5 ± 1.1	< 2	4.9 ± 1.8	< 2

* Observed standard deviation.

Table 10

Correlation of gross beta determinations with
total specific analyses
pCi/l

Trip	Date	Total specific activity y	Gross beta (dissolved solids) x
I	12/01/70	4.3	3.4
II	03/09/71	1.5	3.4
III	09/21/71	.3	3.7
IV	03/14/72	1.6	1.1
V	07/10/72	3.1	1.75
VI	10/31/72	1.3	1.3
VII	02/06/73	.3	1.44
VIII	06/05/73	.7	.9
IX	11/05/73	.3	.89
X	05/14/74	10.1	4.9

Equation Form: $y = a_0 + a_1 x$

$a_0 = -1.43$

$a_1 = +1.9$

Coefficient of determination = .59

Physical Measurements in Water

In order to characterize the lake water, numerous physical measurements and analyses were performed. The primary intent was to scan these physical parameters for any indications of unusual changes which would indicate significant shifts in the dynamic forces which distributed the radionuclides throughout the lake system. Table II summarizes the pH and solids found in the water. Table IJ summarizes the dissolved stable element concentrations.

The data in table II seem to indicate relatively consistent values of dissolved and undissolved solids. No unusual variations are apparent. The pH was observed to vary from a low of 6.7 to a high of 8.1. The data did suggest a seasonal dependency with low pH occurring in the months of February and March and higher pH occurring in July and August. The seasonal variation, approximated with a sine function, showed no difference in predicted versus observed values for nine trips using a paired "t" test and a confidence level of 90 percent. Such modeling serves only to demonstrate the cyclic nature of the pH within a year.

Table IJ demonstrates relatively constant and consistent stable element concentrations. Iron varied sufficiently to bear some comment. Comparison of the iron data to several parameters indicates that the most significant correlation was with the lake discharge rates.

The relationship is expressed as:

$$\text{concentration of Iron} = (\text{Lake Discharge})^{-1}$$

This may indicate that the iron was introduced at a constant rate and was diluted by the rainfall. The other elements were more likely brought into the drainage system of the watershed with similar elemental makeup such that rainfall or flow rates did not affect the concentration.

Table II

Average pH and solids content
of Lake Robinson water

Trip Date	pH	Undissolved Solids mg/l	Dissolved Solids mg/l
I 12/01/70	5.2	17.3	22.2
II 03/09/71	4.7	9.7	16.3
III 09/21/71	5.6	7.9	28.5
IV 03/14/72	5.8	6.6	13.3
V 07/10/72	6.1	3.7	7.9
VI 10/31/72	5.7	10.2	19.8
VII 02/06/73	4.9	9.8	17.2
VIII 06/05/73	5.5	6.9	19.0
IX 11/05/73	5.8	9.1	29.2
X 05/14/74	5.2	5.8	22.5
Average	5.5	8.7	19.9

Table 12

Average stable element concentration
in Lake Robinson water
mg/l

Element	Concentration	Standard Deviation	MDL
Sodium	1.54	.15	3×10^{-1}
Magnesium	.42	.068	3×10^{-1}
Potassium	.46	.077	5×10^{-1}
Calcium	.80	.17	2×10^{-1}
Manganese	.0056	.0064	5×10^{-4}
Iron	.56	.22	1×10^{-1}
Cobalt	.008	.006	3×10^{-4}
Zinc	.020	.009	5×10^{-4}
Strontium	<.005		5×10^{-4}
Cadmium	.004	.003	2×10^{-4}
Cesium	<1.0		1

MDL = Minimum detectable level.

SECTION V

AQUATIC VEGETATION

In observing a lake ecosystem, one important component is vegetation. It is within this component that mineral content of the water and lake bottom interact with sunlight to form the first trophic level of the system. The lake vegetation serves a wide variety of functions such as food sources for aquatic life, habitats for aquatic fauna, benthic stabilizers from the scouring forces of currents, and a source of dissolved oxygen.

Inherent in the nature of plant life is its ability to selectively take minerals from the environment and include them within its organic structure. Such action causes the lake flora to concentrate many of the radioactive elements discharged into the lake as wastes. Such storage action is only temporary since the radionuclides following the patterns of cycling elements transfer from one component to another until they have decayed to a stable elemental form and become a respectable member of the natural nutrient pool.

The vegetation found in Lake Robinson is typical of dark water lakes of that region. Table 13 lists the major aquatic weeds that were observed indigenous to the lake. Of the many species found there Nymphae odorata (white water lily), Najas flexilis (naiad), and Myriophyllum (water milfoil) were most often chosen for field sampling. Sampling instructions were to find about 1 kilogram of vegetation in the vicinity of a 200-liter water sampling site. The preferred vegetation type was a submersed weed. The second preference was given to emersed weeds which had only floating leaves above the water surface. Emergent weeds were taken only as a last resort.

The aquatic vegetation appeared to be a sensitive monitor of the presence of some radioactive wastes. Table 14 compares the confirmation of radioactive waste nuclides in the water and vegetation of the lake. These data suggests that vegetation might be particularly effective for detecting cobalt, manganese, and iodine. Chromium and cesium seemed to be more readily detected by water sampling.

Table 13

Aquatic weeds observed
in Lake Robinson

Genus	Common Name	Character
Nymphae	White Waterlily	emersed
Najas	Naiad	submersed
Myriophyllum	Watermilfoil	submersed
Gramineae (family)	Grass	emersed
Brasenia	Watershield	emersed
Vallisneria	Vallisneria	submersed
Juncus	Creeping Rush	submersed
Eleocharis	Spike Rush	emersed
Typha	Cattail	emersed
Potomogeton	Pondweed	emersed and submersed
Pontederia	Pickeral Weed	emersed

Table 14

Environmental confirmation of radionuclides released in liquid wastes*

Radionuclide	Times Observed in Liquid Waste	Times Observed In Water	Times Observed In Vegetation
^{58}Co	10	7	10
^{60}Co	10	7	10
^{54}Mn	8	4	7
^{51}Cr	5	4	1
^{131}I	6	1	3
^{137}Cs**	6**	5**	9**
^{134}Cs	5	4	1

* Confirmation over 10 trips.
** Occurs in detectable quantities in the environment independent of reactor releases.

Tables 15, 16, 17, and 18 show the average radionuclide contents of aquatic vegetation. The data demonstrate that radionuclide content increases and decreases with releases of radionuclides. (See figure A-3, Appendix F.) The rates of decrease appear to exceed the decay rates of the longer-lived radionuclides. Such behavior implies the presence of a removal action from the vegetation other than that of radioactive decay. Apparently the radionuclide content of vegetation is more a function of the recent history of liquid releases (releases in the last 1 to 6 months) than it is of prior releases. The vegetation does appear to be an effective integrator of some radionuclide releases and, as such, an effective biological monitor of certain radionuclides in water.

Table 15

Radioactive cobalt in Lake Robinson
aquatic vegetation
pCi/kg

Trip Date	Cobalt-58 Dry Wt.	Cobalt-58 Wet Wt.	Cobalt-60 Dry Wt.	Cobalt-60 Wet Wt.
I 12/01/70	5,000	670	390	40
II 03/09/71	44,000	3,200	9,200	640
III 09/21/71	2,800	250	1,400	100
IV 03/14/72	5,200	770	1,200	200
V 07/10/72	74,000	14,000	12,000	2,100
VI 10/31/72	6,200	800	3,100	400
VII 03/06/73	1,900	350	1,400	250
VIII 06/05/73	4,500	360	4,900	420
IX 11/05/73	470	30	2,100	150
X 05/14/74	360	40	1,900	220

Table 16

Radioactive cesium in Lake Robinson

aquatic vegetation

pCi/kg

Trap Date	Cesium-137 Dry Wt.	Wet Wt.	Cesium-134 Dry Wt.	Wet Wt.
I 12/01/70	2,160	240	< 50	< 10
II 03/09/71	3,500	240	< 40	< 3
III 09/21/71	1,000	90	< 50	< 3
IV 03/14/72	880	80	< 60	< 5
V 07/10/72	3,300	890	< 80	< 6
VI 10/31/72	1,400	100	<100	< 8
VII 03/06/73	510	100	< 80	< 13
VIII 06/05/73	1,300	110	< 20	< 5
IX 11/05/73	9,400	800	6,700	570
X 03/14/74	7,800	1,100	3,500	760

Table 17

Radioactive iodine and strontium
in Lake Robinson aquatic vegetation

pCi/kg

Trip Date	Strontium-89 Dry Wt.	Strontium-89 Wet Wt.	Strontium-90 Dry Wt.	Strontium-90 Wet Wt.	Iodine-131 Dry Wt.	Iodine-131 Wet Wt.
I 12/01/70	< 50	< 5	< 10	< 1	< 50	< 10
II 03/09/71	<400	< 30	850	40	1,000	70
III 08/31/71	<100	< 5	850	50	< 50	< 5
IV 05/14/73	<100	< 10	310	30	< 50	< 5
V 07/10/73	<100	< 10	870	150	< 50	< 5
VI 10/31/73	<200	< 50	1,700	130	<100	< 6
VII 03/06/74	100	< 10	780	140	< 50	< 30
VIII 06/05/74	<100	< 10	1,000	90	< 50	< 5
IX 11/05/74	160	30	3,700	70	3,400	280
X 05/14/74	280	40	280	40	4,200	590

Table 18

Radioactive chromium and manganese
in Lake Robinson aquatic vegetation

pCi/kg

Trip Date	Chromium-51 Dry Wt.	Chromium-51 Wet Wt.	Manganese-54 Dry Wt.	Manganese-54 Wet Wt.
I 12/01/70	< 500	< 50	< 50	< 10
II 03/09/71	< 500	< 50	2,000	140
III 06/21/71	2,000	130	< 50	< 5
IV 09/14/71	< 500	< 50	< 50	5
V 07/10/72	4,100	710	2,100	360
VI 10/31/72	<1,000	< 60	410	130
VII 03/06/73	<2,000	<200	490	90
VIII 06/05/73	1,200	100	2,100	180
IX 11/05/73	< 500	< 50	910	60
X 05/14/74	< 500	< 50	520	70

SECTION VI

BENTHIC SEDIMENTS

The lake benthos comprises a component of the lake system which could receive and store significant quantities of radioactive material through sedimentation and through direct chemical transfer from the water such as chemical reaction, ion exchange, and other adhesion actions. Sedimentation is considered to be the primary action contributing to the accumulation that takes place. It consists of suspended solids which have grown through agglomeration to a density sufficient to cause settling. Agglomeration is a scavenging process by which ions, some molecules, and smaller particles are attracted by electrostatic, magnetic, and gravitational forces. Such actions are not unique to radioisotopes, but do effect an accumulation of them and thereby remove some radioactive material from the liquid medium. In addition, dead organic material, detritus, falls to the bottom carrying with it the radioactive material it accumulated in its growth and other active biological processes.

As there is transport into this compartment, there is also removal or disappearance from it. The ever changing parameters of the water such as pH and ionic and elemental concentrations cause varying dissolution interactions between the lake water and the material at the lake floor (10). As radioactive decay takes place the quantity of radioactive material within the compartment further reduces.

This study did not attempt to quantify the inflow and outflow rates of the compartment, but it did attempt to capture pictures of the existing radioactive content of the lake benthos and thereby to infer something of the nature and significance of the lake benthos as a storage compartment. Table 19 summarizes the radionuclide analyses for the dredge sampling locations (figure 11). This table presents only those radionuclides which are obviously originating in the reactor. The only exception is cesium-137 which is present in the general environment as well as produced as a fission product within the reactor. The results of the surveys as given in table 19 indicate that measurable concentrations of these radionuclides not only rise but fall. Figures 12 through 17 show a sequence of data on cobalt that suggests this action.

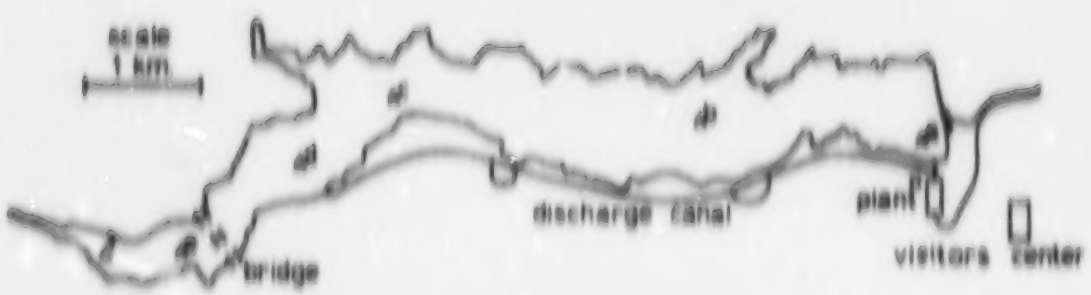
Table 19

Radioactivity in Lake Robinson sediments

pCi/kg (dry weight)

Sediment depth (cm)	Station A	Station B	Station C	Station D	Station E	Station F
	0	0-4	0-7	7-0	0-1	0-0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	No sample
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Based on these results it is believed that buildup of radioactive materials in the benthos sediments of the lake is reduced by an additional removal action other than radioactive decay.



Legend
A : Dredge sampling locations (a-f)
in Lake Robinson

Figure 11. Dredge sampling locations in Lake Robinson

Figure 13. Radioactive cobalt in sediment (position a)

Figure 13. Radioactive cobalt in sediment (position b)

Figure 14. Radioactive cobalt in sediment (position c)

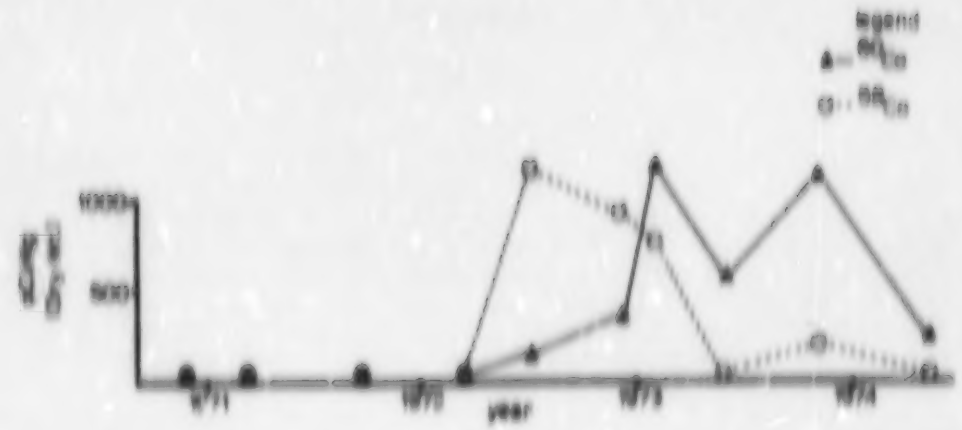


Figure 15. Radioactive cobalt in sediment (position d)

Figure 16. Radioactive cobalt in sediment (position e)

Figure 17. Radioactive cobalt in sediment (position f)

SECTION VII

FISH

In spite of the dark water nature of Lake Robinson, the productivity in the lake appeared to be relatively low. Nutrient levels as recorded in STORET (11) and other qualitative observations seemed to predict this. Conversations with the area game warden suggested that sport catches from the lake were relatively low. There was considerable difficulty in obtaining fish samples from the lake with any consistency. The method of collection was by electrical shocking. The conductivity of the lake water was sufficiently high to restrict the effectiveness of this procedure. As a result of these problems, the available data were limited. Table 20 shows the cesium-137, cobalt-58, cobalt-60, chromium-51, and manganese-54 observed in the samples.

The samples were prepared by grouping the fish according to species. The fish were then dissected into meat, bone, and viscera. In the case of larger specimens, hearts and livers were separated from the other entrails for analyses. Cobalt-58 was identified in specimens of catfish, bream, suckers, largemouth bass, crappie, and drum in the second survey trip. The apparent absence of this radionuclide in Trip I may indicate that accumulation of cobalt in the fish of the lake is at a relatively slow rate; thus, fish are a slow integrating storage component for this radionuclide in this lake.

Table 20

Radioactivity in Lake Robinson fish

pCi/kg (dry weight)

	Trip A	Trip II	Trip III	Trip IV	Trip V	Trip VI	Trip VII	Trip VIII	Trip IX	Trip X
[illegible]	[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]			[illegible]				
[illegible]	[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]			
[illegible]	[illegible]	[illegible]								
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]			
		[illegible]				[illegible]				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
[illegible]	[illegible]		[illegible]							
[illegible]		[illegible]	[illegible]							
[illegible]		[illegible]								
[illegible]								[illegible]		
[illegible]			[illegible]	[illegible]				[illegible]		

0 = Trace detected but less than quantitative sensitivity.

SECTION VIII

SUMMARY AND CONCLUSION

Behavior of Lake Components

In the review of data collected from the system under study, it is clear that measurable quantities of radioactivity accumulate in the lake and its various compartments. Frequently the concentrations are so small that exceptional techniques are required to determine the concentration of radioactivity. This is especially true in the measurement of radioactivity in water. It is important to note that although many samples yielded no detectable content of radioactive waste from the reactor, there did occur some occasions when measurable quantities of such radioactivity were present in each of the lake system compartments: lake water, aquatic vegetation, fish, and benthic sediments. It was, therefore, evident that accumulation did take place.

The lake volume, the rate of cooling water flow from the lake through the reactor and return, and the lake discharge rates all cause the lake water to perform according to a simple mathematical equation. Several unique features of the lake probably aided in effecting the predictable behavior. The low pH of the dark water lake tends to increase the solubility of many waste elements and compounds. The apparent low productivity of the lake limits the storage capacity of the fauna and flora components. The sandy nature of much of the benthic soils limits its ion exchange capacity, thereby reducing the capacity of the benthos to store radioactive wastes. As a result, the mathematical model should provide good predictive values of concentrations. The deviation of the model values from observed concentration values may be attributed to the errors in the liquid waste release data and lake flow data. Therefore, it is believed that the equation 2 is a good model for this system.

$$C = \frac{P_i}{\lambda_{eff,i}} (1-e^{-\lambda_{eff,i} t}) + C_0 e^{-\lambda_{eff,i} t}$$

Further downstream dilution can be simulated by:

$$C = C_L \; e^{-.03x}$$

Due to the variability of lake flows and liquid waste release rates, it is difficult to define a maximum concentration value expected for any radionuclide. Table 21 summarizes expected ranges of concentration in water, using the release parameters presented in the Environmental Impact Statement (9). The upper range limit is calculated on a lake flow of 2.8 m^3/sec a typical "dry" month flow; the average on a flow of 4.7 m^3/sec an average flow; and the lower value for flows of 11.3 m^3/sec typical of a "wet" month flow. This table is not designed to express maximum concentrations which might occur but is to demonstrate a set of typical values which might reasonably be expected.

Table 22 expresses the dose to a swimmer swimming 50 hours in the water at the concentrations of table 21. Fifty hours was chosen as a realistic and convenient seasonal exposure for an individual. The dose expressed in table 22 also represents that of 100 hours of fishing, boating, and/or water skiing on the lake since these activities represent a 2 π geometrical exposure as compared to a 4 π exposure from swimming.

The concentrating effects of vegetation appeared to be quite significant for many of the radionuclides occurring in the liquid wastes. On several survey trips the radionuclides were easily detectable in vegetation but not detectable in the water directly.

The apparent concentration factors of the vegetation demonstrated a high degree of variability which was difficult to interpret. The obvious behavior demonstrated by the vegetation was an apparent transfer of radioactivity back to the water as the water concentration of absorbed radionuclides decreases. Such action modifies the extent of a long-term buildup over the years.

Fish data, like vegetation, indicate a responsive rise and fall of radionuclide concentrations with those of water. Again such behavior suppresses a gradual long-term rise in radionuclide concentrations independent of lake water concentrations.

Table 21

Projected range of equilibrium concentrations
at various lake flows
pCi/l

Nuclide	2.8 m^3/sec (dry month)	4.8 m^3/sec (avg. month)	11.3 m^3/sec (wet month)	Highest Lake Average Observed
^{3}H	1.1 x 10^3	.55 x 10^3	.25 x 10^3	3.7 x 10^3
^{51}Cr	.10	.08	.06	2.2
^{54}Mn	.12	.07	.04	.15
^{58}Co	1.9	1.36	.87	1.8
^{60}Co	.47	.34	.12	.2
^{89}Sr	.05	.04	.03	.27*
^{90}Sr	.005	.0024	.0012	5*
^{131}I	7.3F	6.91	6.12	4.5
^{134}Cs	9.89	5.62	2.73	2.4
^{137}Cs	10.1	5.06	2.54	3.2

*This concentration is found in the general environment and cannot be wholly attributed to releases from this facility.

Table 22

Projected range of doses to an adult swimming 50 hours* in expected concentrations (mrem to whole body)

Nuclide	Dry Month	Avg. Month	Wet Month	Highest Lake Concentrations Observed
^{3}H	-0-	-0-	-0-	-0-
^{51}Cr	2.6×10^{-7}	2.1×10^{-7}	1.6×10^{-7}	9.7×10^{-6}
^{54}Mn	9.0×10^{-6}	5.3×10^{-6}	3.0×10^{-6}	1.1×10^{-5}
^{58}Co	1.7×10^{-5}	1.2×10^{-5}	7.8×10^{-6}	1.6×10^{-5}
^{60}Co	1.1×10^{-5}	5.5×10^{-6}	3.8×10^{-6}	4.6×10^{-5}
^{89}Sr	1.2×10^{-6}	9.2×10^{-7}	6.9×10^{-7}	6.3×10^{-6}
^{90}Sr	1.4×10^{-10}	6.5×10^{-11}	3.2×10^{-11}	1.4×10^{-7}
^{131}I	2.5×10^{-5}	2.3×10^{-5}	2.1×10^{-5}	1.5×10^{-5}
^{134}Cs	1.4×10^{-5}	8.1×10^{-6}	4.0×10^{-6}	3.5×10^{-5}
^{137}Cs	5.1×10^{-5}	2.5×10^{-5}	1.3×10^{-5}	1.6×10^{-4}
Total	2.4×10^{-4}	1.5×10^{-4}	8.5×10^{-5}	8.8×10^{-4}

* The dose expressed also represents that of 100 hours of fishing, boating or water skiing.

Benthic sediments demonstrate an ability to release their stored radionuclides. Such action again reduces any extended storage in this component of the system.

This particular lake system stores the bulk of the liquid radioactive waste in the same manner that it would any solute. As such, it tends to make maximum use of downstream transport and dilution. If one assumes that dispersion and dilution are desirable qualities of such a system, this particular system offers many advantages.

1. The low pH probably increases the solubility of many of these waste products and thereby insures a longer retention in the soluble state.

2. The low productivity of the lake limits the fish available for sportsmen and human intake.

3. The water is not of a quality desirable for potable uses. Since it is not used in this manner another potential pathway of human exposure is avoided.

4. The region does not generally require this water for agricultural irrigation and thus avoids another radionuclide pathway to man.

Surveillance Techniques

From experiences in the conduct of this study several surveillance techniques were found effective in evaluating the aquatic environment. It was demonstrated that in-plant source monitoring was of great value in guiding the analytical techniques to achieve a maximum sensitivity for the radionuclides released. It was invaluable to know the relative probability of the presence of volatile nuclides like iodine in advance of sample preparation to preclude any loss of activity by the sample preparation procedures. The procedure of proportional compositing liquid wastes as an independent monitor of waste release rates was of similar value. Such procedures validated the operator's waste release data.

In the analysis of lake water the advantage of ion exchange columns to improve sensitivity was demonstrated. This technique was reported by Nasuike and Windham (12). This technique increased analytical sensitivity by a factor of eight or more compared to usual techniques. Such increased sensitivity provided crucial positive measurements which otherwise would have been missed using former techniques.

The analysis of vegetation tended to indicate that qualitative monitoring of a body of water might be accomplished from this data. It was observed that aquatic vegetation should be surveyed, mapped, and identified prior to establishing the sampling protocol. In the accomplishment of this, divers should be used to acquaint surveyors with the location, prevalence, and identity of submerged vegetation. The latter is probably the most desirable sample source and is often ignored otherwise.

Representative sampling of the aquatic fauna proved to be the most difficult task to achieve. Due to the mobility of the fish, the wide variety of species and habitat preferences, and apparent paucity of population, this task was not accomplished to the degree desired. The conductivity of the water in this lake limited the effectiveness of electrical shocking. Rotenone poisoning appeared too drastic a procedure. Netting or other trapping techniques would have provided an insufficient sample size and a highly biased species distribution.

Sampling of benthic sediments offered significant problems in portions of the lake where submerged sticks, limbs, and debris lined the bottom. This material caught in the jaws of the Peterson dredge and prevented its containment of a sediment sample. In many cases numerous dredging attempts were performed to collect the sample. Operationally, a winch system to operate the dredge was a necessity. It is felt that use of a diver to locate an underwater marked location and perform a stringently controlled sample collection procedure might have reduced some sample variability.

An underwater gamma probe was used to survey regions where elevated concentrations of sediments might be found. In this particular lake this procedure was not sufficiently productive to warrant discussion of any positive results. Such procedures in other studies (1) have been extremely helpful and should be evaluated in any similar surveillance activity.

Conclusion

The buildup concentrations of long-lived radionuclides observed in Lake Robinson are detailed in the appropriate tables. The rate of radionuclide turnover in the components other than the water was too rapid to quantitatively determine in this study.

Since the buildup rates appeared to be highly responsive to waste discharge rates, lake flow, and exchange rates between the component and the system, no "life-of-the-reactor" effect could reasonably be evaluated. At any given point in time concentrations of radionuclides from the reactor as they occur in the lake water and other lake components are primarily a function of the history of the parameters for the previous year and are essentially independent of any older history.

Table 32 summarizes reasonably expected annual external radiation doses to individuals engaging in swimming, boating, or fishing. These data are calculated on release rates presented in the EIS (9). A reasonable estimate of dose to an individual who swam, fished, and/or water skied in the lake would be about 5 microrem per year, an imperceptible quantity when compared to background and other potential exposures.

REFERENCES

1. UNITED STATES NUCLEAR REGULATORY COMMISSION, Title 10, Code of Federal Regulations, Part 50, Licensing of Production and Utilization Facilities, Appendix I, United States Printing Office, Washington, DC 20402 (April 1975).

2. UNITED STATES ATOMIC ENERGY COMMISSION, Title 10, Code of Federal Regulations, Part 20, Standards for Protection Against Radiation, par. 20.105 (a), Division of Radiation Protection Standards, U. S. Atomic Energy Commission, Washington, DC 20545 (August 1969).

3. INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Report of Committee II on Permissible Dose for Internal Radiation (1959), ICRP, Publication 2, pp. 27-34, International Commission on Radiological Protection, Pergamon Press, Oxford (1967).

4. CAROLINA POWER AND LIGHT COMPANY, Final Facility Description and Safety Analysis Report, Volumes 1 and 2, USAEC Docket No. 50-261, Carolina Power and Light Company (November 1968).

5. RUTTNER, FRANZ, Fundamentals of Limnology, pp. 190-197, University of Toronto Press, Toronto (1953).

6. U. S. DEPARTMENT OF INTERIOR, Daily Discharge Tables of Gage Station 02130910 at Black Creek near Hartsville, SC, October 1968 to September 1974, Geological Survey, Water Resources Division, U. S. Department of the Interior, Columbia, SC.

7. CAROLINA POWER AND LIGHT COMPANY, H. B. Robinson, Unit No. 2, Operating Reports 1 - 9, Carolina Power and Light Company (1970 - 1974).

8. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, Public Health Service, National Center for Radiological Health, Public Health Evaluation of H. B. Robinson Unit No. 2, RT-67-2, National Center for Radiological Health, Rockville, Maryland 20852 (January 1967).

9. UNITED STATES NUCLEAR REGULATORY COMMISSION, Office of Nuclear Regulation, Final Environmental Statement related to the operation of H. B. Robinson Nuclear Steam-Electric Plant Unit 2, NUREG-75/034 (April 1975).

10. SAIO, ANNELI, and RITVA SAXEN, On the Role of Humic Substances in the Transport of Radionuclides, Report SFL-A30, Institute of Radiation Physics, Helsinki, Finland (December 1974).

11. ENVIRONMENTAL PROTECTION AGENCY, Preliminary Report on Lake Robinson, Darlington, and Chesterfield Counties, South Carolina, (Draft) STORET No. 4508, National Eutrophication Survey, National Environmental Research Center, Las Vegas, NV (November 1974).

12. HASUIKE, J. K. and S. T. WINDHAM, Construction and Operation of an Ion Exchange Cartridge for Monitoring Radionuclides in the Environment, ORP/SEPF 73-2, Eastern Environmental Radiation Facility, Environmental Protection Agency, Montgomery, AL (June 1973).

13. WINDHAM, SAM T. and C. R. PHILLIPS, Radiological Survey of New London Harbor, Thames River, Conn. and Environs, Radiation Data and Reports, 14:659-666 (November 1973).

Appendix I

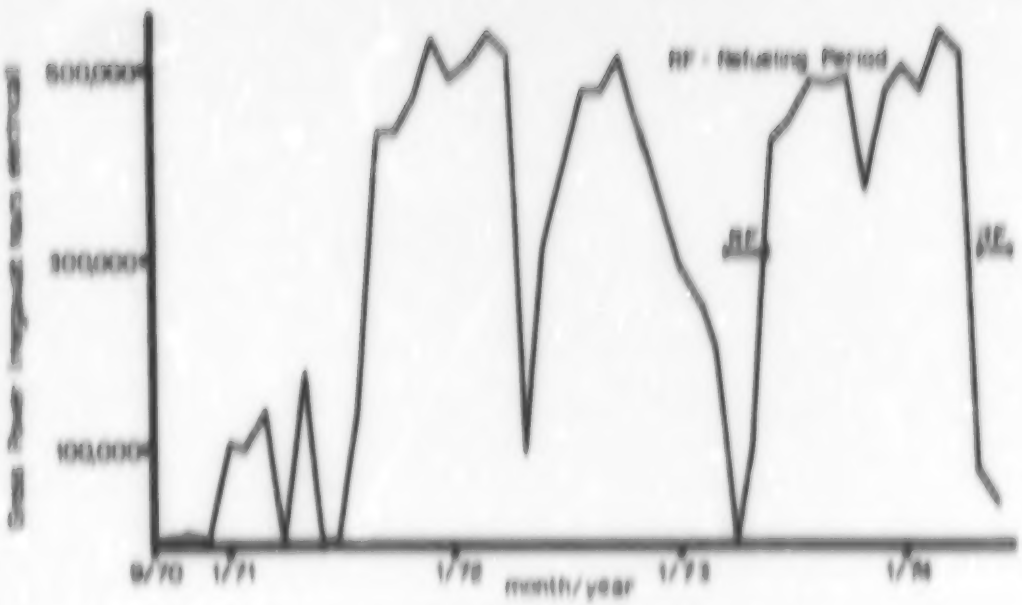


Figure A-1. Gross power generated (7)

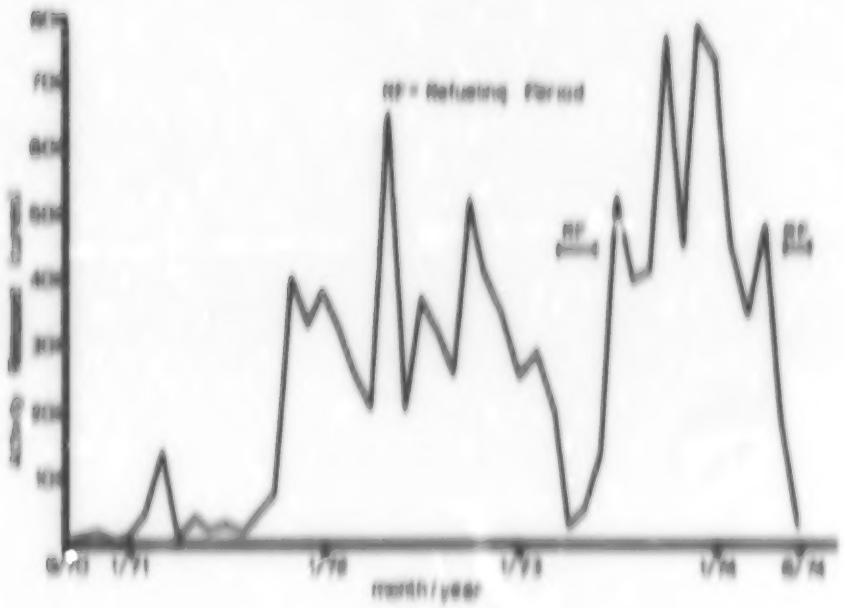


Figure A-2. Liquid radioactive waste releases of tritium (7)

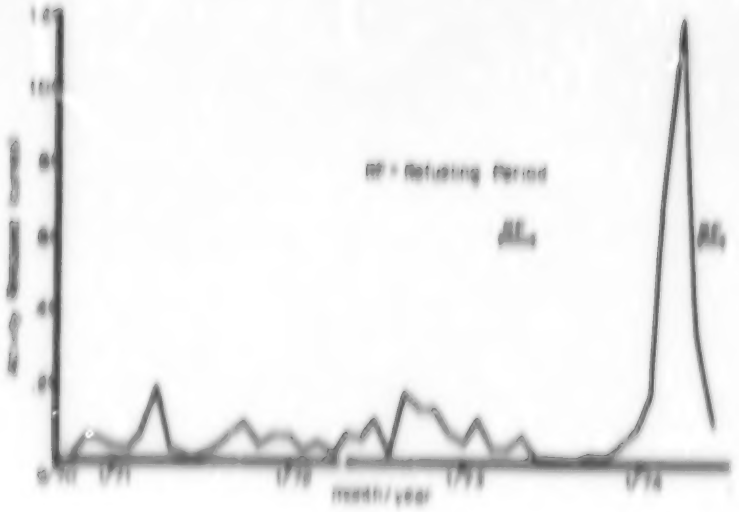


Figure A-3. Liquid radioactive waste releases - non-tritium (7)

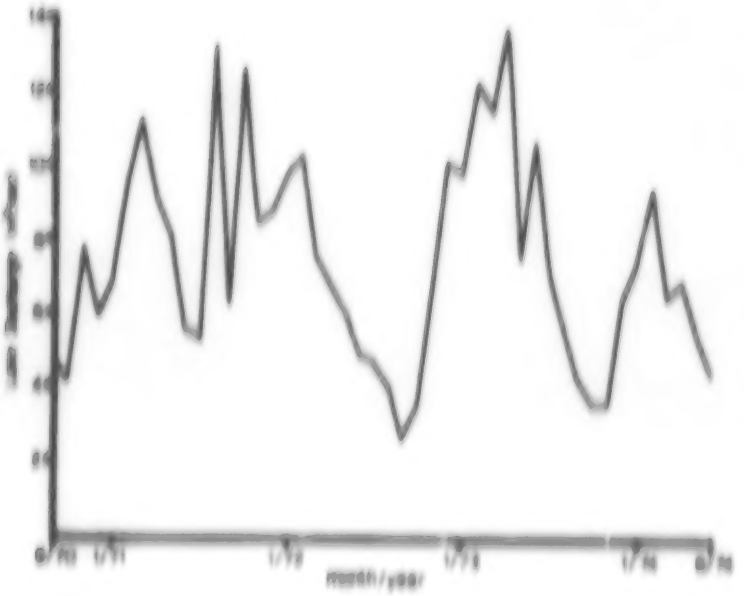


Figure A-4. Lake Robinson discharge rates (6)